IPN Progress Report 42-192 • February 15, 2013

Reducing Near-Field RF Levels and Noise Temperature on a 34-m Beam-Waveguide Antenna by Strut Shaping

Behrouz Khayatian,* Daniel J. Hoppe,* Michael J. Britcliffe,* and Eric Gama*

ABSTRACT. — Strut shaping of NASA's Deep Space Network (DSN) 34-m beam-waveguide (BWG) antenna has been implemented to reduce near-field RF exposure while improving the antenna noise temperature. Strut shaping was achieved by introducing an RF shield that does not compromise the structural integrity of the existing structure. Reduction in the RF near-field exposure will compensate for the planned transmit power increase of the antenna from 20 kW to 80 kW while satisfying safety requirements for RF exposure. Antenna noise temperature was also improved by as much as 1.5 K for the low elevation angles and 0.5 K in other areas. Both reductions of RF near-field exposure and antenna noise temperature were verified through measurements and agree very well with calculated results.

I. Introduction

A 20-kW X-band (7.165-GHz) transmitter on a 70-m antenna provides the highest power uplink capability for telecommunications in the Deep Space Network (DSN). The DSN would like to replicate this capability on its 34-m beam-waveguide (BWG) antennas. A proposal [1] to provide the same equivalent isotropic radiated power (EIRP) has been made. EIRP is proportional to the directivity (and therefore the area) of an antenna; therefore, employing a transmitter with four times the power of that on a 70-m antenna enables equivalent uplink performance on a 34-m BWG. For the DSN, this requires having an 80-kW transmitter on a 34-m antenna. However, with 80 kW, we find that there are areas at ground level where power density exceeds safety limits, requiring a larger personnel exclusion zone for all 34-m antennas. In order to eliminate the larger exclusion zone on the ground near the antennas, which will add additional cost and personnel constraints, a solution is sought to minimize spurious scattering of the antenna structure in the near vicinity on the ground in front of the antenna. In this study, the near-field area of interest is in the plane parallel to the ground in front of and ranging from 20 to 300 m away from the antenna aperture and from ±60 m from the antenna center-line, as represented in Figure 1.

---

* Communications Ground Systems Section.

The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

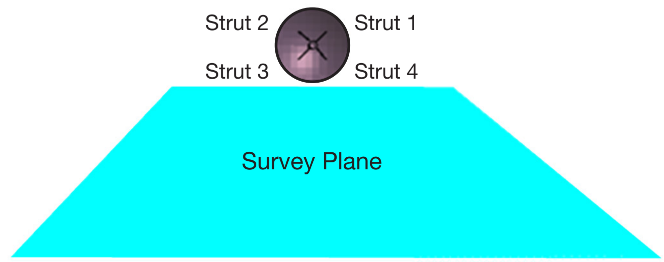

Figure 1. A 34-m BWG antenna with respect to the ground plane in front of the antenna called the survey plane.

During the course of this design, we have made sure that all other important antenna performance parameters are unchanged or improved. As an added benefit to minimizing the RF ground illumination levels on transmit, the antenna noise temperature, which is a strong function of ground illumination, is simultaneously reduced if near-field ground exposure is minimized. In [2], an analysis of the near-field of a 34-m antenna was presented. Furthermore, a comparison between the calculated and measured near-field intensity of the antenna was made over a survey plan similar to the one shown in Figure 1. The near-field signature of the 34-m antenna is computed in [2]; however, the observed features of the power density on the ground were not associated with the physical scattering mechanism of the antenna structure.

Antenna noise improvement is addressed in [3] by designing a low-backscattering strut on the Research and Development antenna at DSS-13, another 34-m BWG antenna with a different strut configuration (see [4]). It is shown in [3] that the antenna noise temperature is improved between 0.2 K and 1.1 K over the elevation angles.

In this article, we explore scattering mechanisms from the antenna and associate them with the ground signature of the power density. Accordingly, we will focus on the structural elements that need to be redesigned, a process that requires reviewing a number of candidates to solve the near-field intensity reduction. Furthermore, the associated antenna noise temperature will also be evaluated to make sure that the proposed design can also improve this important performance parameter.

II. Existing Strut Structure and Proposed Modifications

Figure 2 shows the 34-m BWG subreflector and its structural support, including its struts configuration. The strut structures are composed of a pair of beams supported by cross-members connecting two beams. Our goal is to leave the structural integrity of the supporting struts intact by introducing RF shields that place the struts completely in the shadow region of the shields. Furthermore, the size of RF shield should not reduce the effective radiating area of the antenna aperture due to shadowing.

III. Scattering Mechanism and Structural Elements

Figure 3 shows the most significant ray contributions in the near-field pattern, and Figure 4 shows the corresponding RF ground signature calculated by physical optics/physical theory

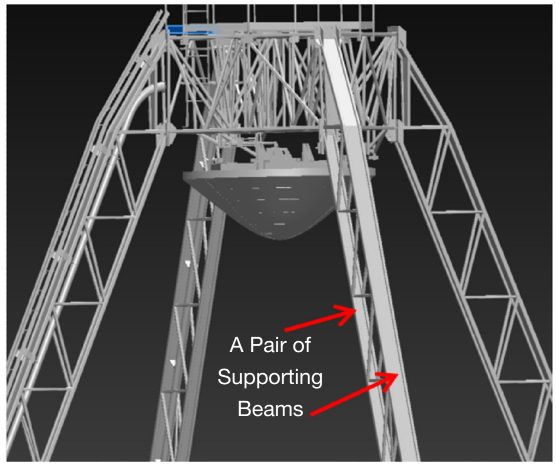

Figure 2. Mechanical drawing of the 34-m BWG subreflector and its associated supporting struts.

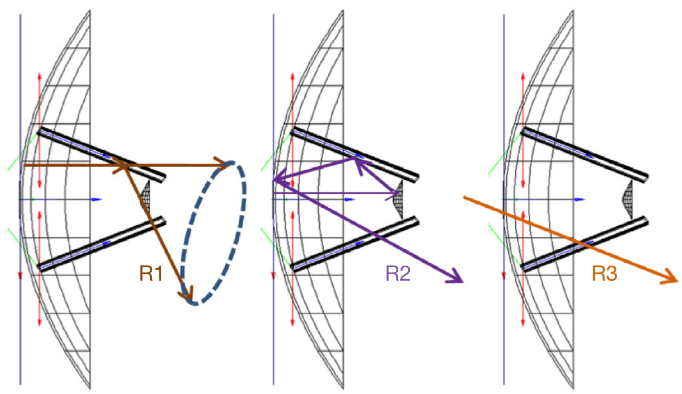

Figure 3. Major contributing rays to near-field ground signature.

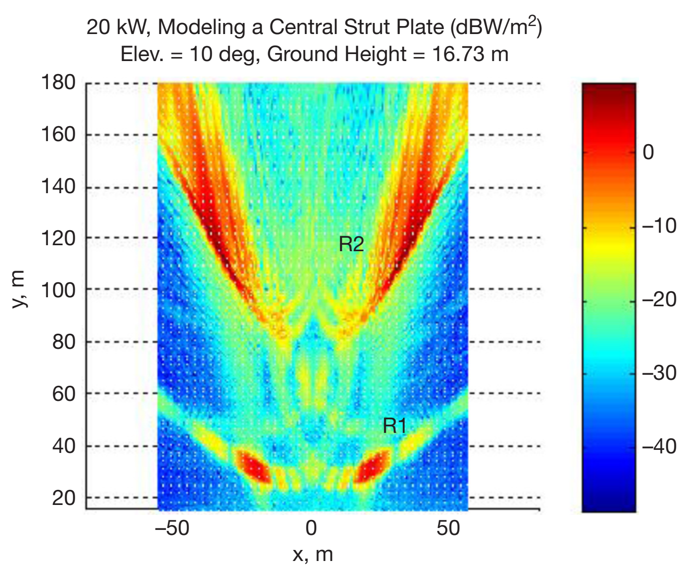

Figure 4. Near-field ground illumination and the associated scattering mechanism defined by R1 and R2.

of diffraction (PO/PTD) using GRASP.[1] It should be noted that the calculation in Figure 4 is at about 1.5 m above the ground level and reflection from the ground is ignored in this calculation. In Figure 3, contribution R1 is from the plane wave from the main reflector that is reflected/diffracted by the struts. The cone shown in Figure 3 is due to contribution of the diffracted rays from the strut edges. Contribution R2 is due to subreflector illumination of the struts and subsequent reradiation by the main reflector, and contribution R3 is the direct feed spillover contribution. A preliminary analysis shows that 1 percent and 3.2 percent of the total feed radiation illuminate the struts due to R1 and R2, respectively (R3 contribution is negligible compared to the other two). It can be shown that only the top two struts (struts 1 and 2 shown in Figure 1) contribute significantly to the ground illumination. This was verified by removal of struts 3 and 4 from the calculations and obtaining the same result as that of the case when all struts were present in the calculations. Therefore, the bottom two struts (struts 3 and 4) require no modification, and will remain unchanged in both at the experimental verification of the strut scattering modifications and the final implementation.

IV. Analytical and Preliminary Design Considerations

In order to reduce computational effort described in [2], a simplified strut model was employed here, where the two-beam strut was reduced to an equivalent single beam located half way in the middle of two beams, as shown in Figure 5. It was shown that a single beam reduces the computational complexity involving multiple interactions between beams but still results in a similar near-field behavior, as was reported in [2]. Figure 4 is computed using a simplified RF model and compares well to what is reported in [2].

In Figure 4, the R2 lobes are the result from the reflected rays from the subreflector mapping on a narrow strip along the main reflector. Therefore, to smear and diffuse those lobes on the ground, we seek to sweep the strut-reflected fields over a wider angular range or redirect them above the horizon if possible. This can be achieved by introducing an RF shield using a 90-deg wedge or a half cylinder, as shown in Figure 6. Either one of these configurations would spread the reflected energy from the struts over a wide angle, which lowers the overall power density on the ground. According to our calculations, a 90-deg wedge or a half cylinder will reduce the maximum field intensity by nearly 10 dB. This reduction is more than adequate to compensate for the power increase in the DSN operation from 20 kW to 80 kW (~6 dB).

On the other hand, realizing that each side of the 90-deg wedge in Figure 6 directs the reflected fields into different portions of the reflector, one can decompose the wedge into two edges, as seen in Figure 7. Furthermore, the edge angle α can be varied to optimize the overall antenna performance. This was implemented in the final shield design, which is described next.

[1] GRASP 9.4, a general reflector antenna analysis software by TICRA Engineering Consultants, Copenhagen, Denmark.

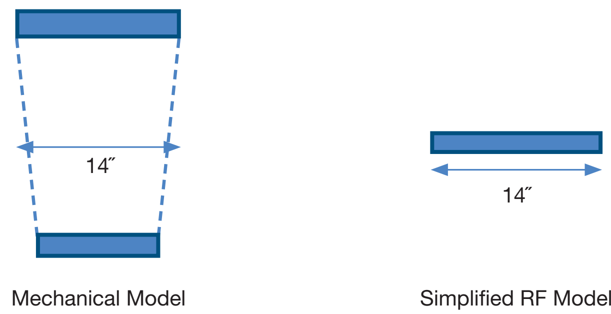

Figure 5. End view cross-section of mechanical strut model and the simplified RF model.

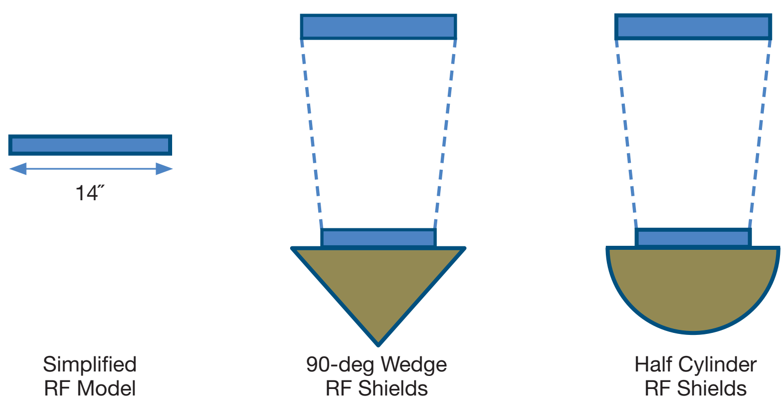

Figure 6. A pictorial representation of RF shields and their placement with respect to the supporting beams.

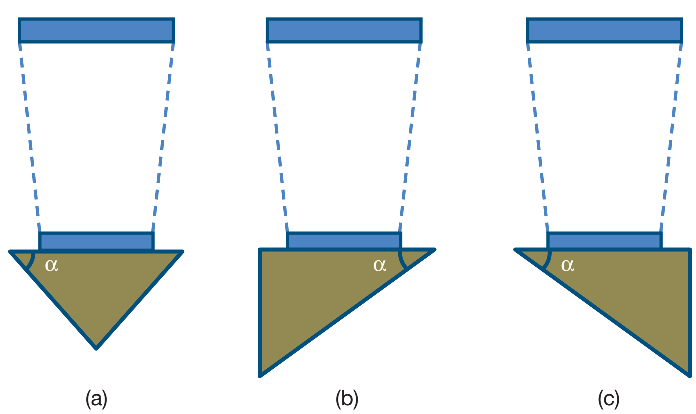

Figure 7. A wedge-shaped RF shield (a) covering the two beams of the strut structure and its decomposition into two individual edges or similar edge angles (b) and (c).

V. Final Design and Performance Verification

The implemented design of the RF shield is shown in Figure 8. A 30-deg RF shield is used to place the two-beam strut structure in its shadow region. Note that the 30-deg wedge angle is pointing toward the top of the main reflector. In other words, the RF shield on the top left strut in Figure 8 is similar to that of Figure 7(b), while the RF shield on the top right strut in Figure 8 is similar to that of Figure 7(c). Had the edges been placed the opposite way (that is, pointing to the side of the reflector), undesirable high-intensity lobes would reappear on the ground due to the particular illumination of the main reflector. Further note that only the upper two struts are covered in this design for the reasons discussed earlier in this article. The calculated near-field ground signature using a 30-deg edged RF shield is shown in Figure 9. Comparing to Figure 4, we note that all significant far-out lobes have disappeared. As a result, ground illumination in the region far from the aperture is reduced by more than 15 dB. Furthermore, the total ground scattered power with and without the RF shield is reduced by nearly a factor of 6, promising lowered overall antenna noise temperature.

To validate this analysis, RF shields were manufactured from lightweight material (0.125-in. Al) and were installed at DSS-26, a 34-m BWG antenna at NASA's Goldstone DSN complex in California. A measurement of ground illumination was taken before and after installation of the 30-deg RF shields (Figure 10). Note that Figure 10(a) represents a measurement matching that of the calculation shown in Figure 4 for the existing antenna configuration, so Figure 10(b) matches that of Figure 9 after placing the RF shields. The measurement was completed using a number of Narda Field Strength Meters, NBM-550. Four personnel surveyed the designated area in sections with probes held approximately 1.5 m above the ground level.

Measurement after the modification clearly displays the removal of the far-out lobes. Differences between calculated and measured results can be attributed to several factors, including uneven ground elevation, field sample/averaging by the meter, and the terrain vegetation not considered in the analysis. Furthermore, the measured pattern corresponds to an actual antenna elevation of 11 deg plus an additional ground slope of 3 deg away from the antenna, which is the primary factor in the location of far-out lobes visible in Figure 10(a).

To further verify that the strut modification has not degraded the key antenna noise temperature parameter, the antenna noise temperature vs. antenna elevation angle was measured at 8.42 GHz and is displayed in Figure 11. The noise temperature near the design point at low elevation angles (10 to 15 deg) is significantly improved by as much as 1.5 K as a consequence of reducing near-field ground illumination. Furthermore, noise temperature is reduced by more than 0.5 K over the entire range of the elevation angles due to the reduction in strut scattering.

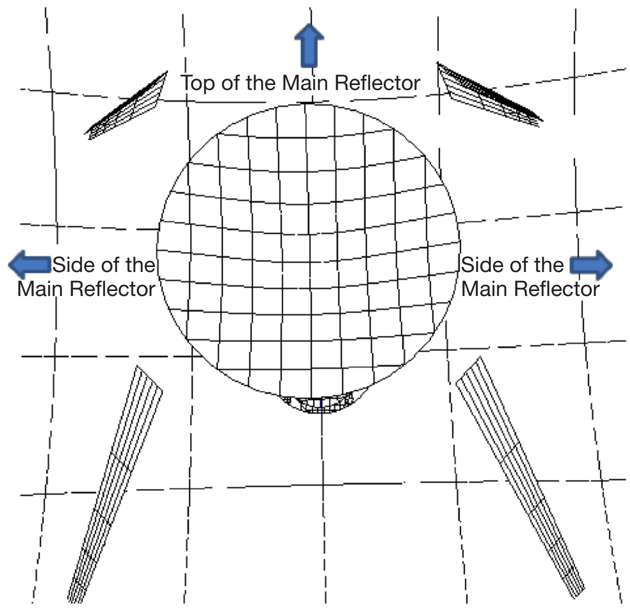

Figure 8. Realized 30-deg edged RF shields with respect to the subreflector and strut structure.

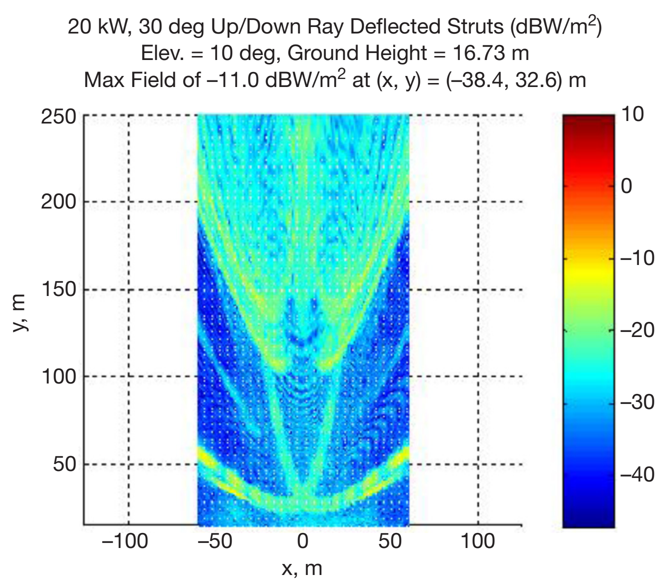

Figure 9. Near-field ground illumination after placing the 30-deg RF shield.

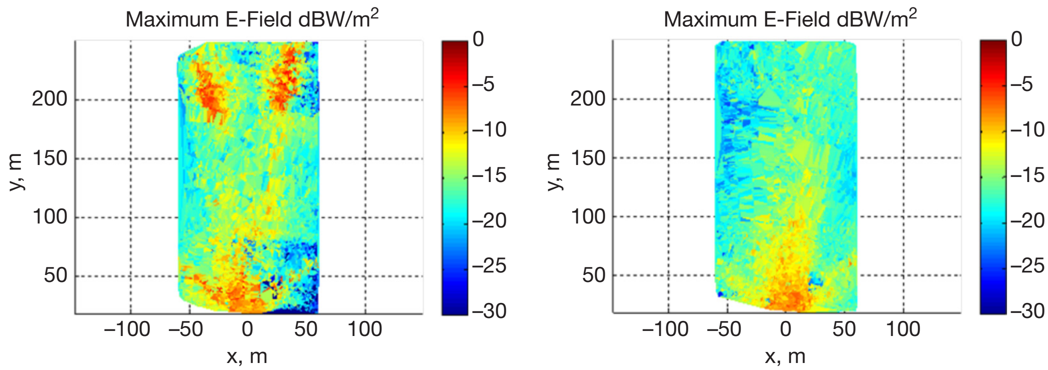

Figure 10. A comparison between near-field ground illumination before (a) and after (b) placing the 30-deg RF shields.

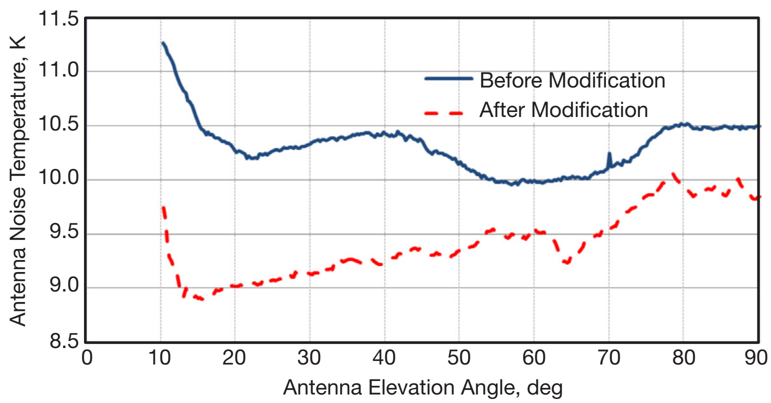

Figure 11. Measurement of noise temperature vs. antenna elevation.

VI. Conclusion

The strut structure of NASA's DSN 34-m BWG antenna was modified by introducing an RF shield that reduces near-field RF exposure on the ground while simultaneously improving the antenna noise temperature.

The RF shield is a low-cost solution that maintains the structural integrity of the mechanical support. The RF ground exposure is reduced by nearly 15 dB in the far-out lobes. This is more than adequate to offset for the planned operational transmit power increase of the DSN 34-m antenna from 20 kW to 80 kW. Furthermore, the RF shields have reduced the antenna noise temperature between 0.5 K to 1.5 K over the entire range of antenna elevation angles.

Acknowledgments

The authors would like to acknowledge contributions from Manuel Franco, Wendy Hodgin, and DSN site personnel for their assistance in the measurements and Stephen Slobin for processing the noise temperature data.

References

[1] D. J. Hoppe, B. Khayatian, and J. B. Sosnowski, "The Deep Space Network's X/X/Ka Feed: Modifications for 100 kW CW Uplink Operation," IEEE Antennas and Propagation Society International Symposium (APSURSI), pp. 3032–3036, Toronto, Canada, July 11–17, 2010.

[2] V. Jamnejad and N. Llombart Juan, "An Analysis of Near Fields of 34-m Antennas of JPL/NASA Deep Space Network," Antennas and Propagation Society International Symposium (APSURSI), pp. 3011–3014, Spokane, Washington, July 3–8, 2011.

[3] A. Prata, Jr., F. J. S. Moreira, M. A. Thorburn, T. D. King, C. Stelzried, and S. J. Keihm, "Measurement of the Noise Improvement of a 34-meter Cassegrain Antenna Retrofitted with a Low-Backscattering Strut," IEEE Antennas and Propagation Society International Symposium (APSURSI), 1997 Digest, vol. 3, pp. 1659–1662, Montreal, Quebec, July 13–18, 1997.

[4] W. A. Imbriale, *Large Antennas of the Deep Space Network*, Wiley-Interscience, February 5, 2003. Also available electronically: Deep-Space Communications and Navigation Systems Center of Excellence (DESCANSO) Deep-Space Communications and Navigation Series, Jet Propulsion Laboratory, Pasadena, California, February 2002. http://descanso.jpl.nasa.gov/Monograph/series4/Descanso_Mono4_web.pdf